Indications for Factorization and Re $V_{ub} < 0$ from Rare B Decay Data

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Abstract

Surveying known hadronic rare B decays, we find that the factorization approximation can give a coherent account of $K\pi$, $\pi\pi$ and $\rho^0\pi^+$ data and give predictions for $\omega^0\pi^+$, $\rho\pi$ and $K^*\pi$ modes, *if* $Re\,V_{ub}$ *is taken as negative* (in standard phase convention) rather than positive. As further confirmation, we expect a lower $\sin 2\beta$ value at B Factories as compared to current fits, and B_s mixing close to LEP bounds at SLD and CDF.

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The last few years have been quite exciting for the field of hadronic rare B decays [1]. The observation of exclusive $B \longrightarrow \eta' K^+$, $\eta' K^0$, $K^+\pi^-$, $K^0\pi^+$, and $K^+\pi^0$ modes give definite support for $b \to s$ penguins, while ωh^+ [2] and especially the newly observed $\rho^0\pi^+$ mode [3] indicate that tree level hadronic $b \to u$ transitions do occur. In contrast, the limits on ϕK^+ and $\pi^+\pi^-$, $\pi^+\pi^0$ modes are rather stringent [1,4]. Faced with the questions raised by these measurements, together with the fact that two new B Factories would turn on this year, there is a sense of urgency for us to reach better understanding of these modes.

Admittedly, much uncertainty clouds the theory of hadronic rare B decays. The effective Lagrangian that describes b quark decay is better understood, but the subsequent evolution of the decayed B meson into specific *light* two body hadronic final states is certainly very complicated, while our understanding of long distance QCD is limited. The usual approach is to assume factorization, then use parameters such as $N_{\rm eff.} \neq N_C \equiv 3$ to fit and quantify the apparent deviations from this assumption. The picture is further muddled by the possibility of rescattering between hadronic final states (FSI). Attempts have been made [5] to take most uncertainties into account and project into the future on the many effective two body modes, where the experimental outlook is rather bright. But, can the navigation chart be simplified? In this Letter we make such an attempt at understanding present data.

We find a simple, coherent and therefore attractive view that can account for current trends in data, especially $K\pi$, $\pi\pi$ and $V\pi$ ($V = \rho$, ω and K^*) modes: Naive factorization works without resort to $N_{\rm eff.}$ or FSI, but *only with* $\cos\gamma$ *negative*, where $\gamma = \arg(V_{ub}^*)$ in the standard phase convention [6]. Smaller light quark masses may also help. Semi-quantitative predictions can be made which could be tested in the near future.

Current fits [6,7] to the KM matrix elements, however, seem to favor $\cos\gamma > 0$. The preference comes largely from the limit on $\Delta m_{B_s}/\Delta m_{B_d}$ where the hadronic uncertainty is restricted to $\xi^2 \equiv f_{B_s}^2 B_{B_s}/f_{B_d}^2 B_{B_d}$, which is probably the least uncertain. With the more conservative $\Delta m_{B_s} > 10.2$ ps^{-1} [6] at 95% C.L., which also corresponds to the current best single experiment sensitivity, some room is allowed for $\cos\gamma < 0$. But with $\Delta m_{B_s} > 12.4$ ps^{-1} [7] from combining LEP, CDF and SLD data, one gets $\gamma \simeq 60$–70° with $\sim 10^\circ$ errors,

and $\cos\gamma$ seems definitely positive. We note that the 95% C.L. contour of one of the fits [7] has a tail extending towards $\cos\gamma < 0$, and would extend further if one enlarged the error on ξ. It may be prudent, therefore, to allow for the possibility that $\cos\gamma < 0$ might still be the case in Nature. The current fit result may be implying that B_s mixing is not far around the corner. In any case we should keep in mind that γ is the most challenging unitarity angle to measure at B Factories, and any handle one may gain should be welcome.

When 1997 data suggested $K^0\pi^+ > K^+\pi^-$, a method for constraining γ was proposed [8]. With 1998 data, the $K^+\pi^0$ mode was observed while the $K^0\pi^+$ rate came down [1], and both branching ratios (Br) are now similar to $K^+\pi^- \simeq 1.4\times10^{-5}$. Although the method of Ref. [8] is no longer effective, it was pointed out [9] that the 1998 data suggest $\cos\gamma < 0$ [10] and prefer small or no FSI phase. Following this trail, we find that a negative $\cos\gamma$ could also explain the absence of the $\pi^+\pi^-$ mode, the prominence of $\rho^0\pi^+$ over $\omega^0\pi^+$ and $K^{*0}\pi^+$, as well as predict emerging trends in $\pi\pi$, $\rho\pi$ and $K^*\pi$ modes.

Let us retrace the main points of Ref. [9]. We give the average $K\pi$ branching ratios vs. γ in Fig. 1(a) for $m_s = 105$ and 200 MeV. The light quark mass m_s enters through the penguin O_6 operator via relations between axial current and pseudoscalar density matrix elements. We see that $K^+\pi^- \simeq K^0\pi^+ \simeq K^+\pi^0$ prefers a larger m_s, and can only be achieved (allowing for some experimental uncertainty) for $\gamma \sim 90^\circ - 130^\circ$, or $\cos\gamma < 0$. Although [9] the electroweak penguin (EWP) plays a crucial role in raising the $K^+\pi^0$ rate, the change in sign of $\cos\gamma$ was important in allowing $K^+\pi^-$ to reach above $K^0\pi^+$.

With present fit values for V_{ub}, one expects $\pi^+\pi^0 < \pi^+\pi^- \sim 1\times10^{-5}$. Instead, one finds $\pi^+\pi^- < 0.84\times10^{-5}$ [4] and a weaker limit on $\pi^+\pi^0$ due to a larger event yield. Compared to the strength of the $K\pi$ modes, they pose some problem for theory. Again, the traditional approach is to resort to $N_{\text{eff.}}$ or FSI, or a smaller $|V_{ub}|$. We find, rather interestingly, that a simple flip in sign of $\cos\gamma$ not only explains the smallness of the $\pi^+\pi^-$ mode, but also allows for $\pi^+\pi^0 > \pi^+\pi^-$, without need for very small $N_{\text{eff.}}$ or large $\pi^+\pi^- \to \pi^0\pi^0$ rescattering [11]. The amplitude for the $\bar{B}^0 \to \pi^+\pi^-$ mode is,

$$\sqrt{2}\,\mathcal{A}_{\pi^+\pi^-} = iG_F f_\pi F_0\,(m_B^2 - m_\pi^2)\,\{V_{ud}^* V_{ub}\,a_1 - V_{td}^* V_{tb}[a_4 + a_{10} + (a_6 + a_8)R_1]\}\,, \qquad (1)$$

where $F_0 = F_0^{B\pi}(m_\pi^2)$ is a $B \to \pi$ (BSW) form factor, a_i's are combinations of Wilson coefficients [5], and $R_1 = 2m_\pi^2/(m_b - m_u)(m_u + m_d)$. It is clear that tree–penguin (T–P) interference for $K\pi$ and $\pi\pi$ modes differ in sign, because the KM factors $\mathrm{Re}\,(V_{ts}^* V_{tb}) \cong -A\lambda^2$ and $\mathrm{Re}\,(V_{td}^* V_{tb}) \cong A\lambda^3(1-\rho)$ have opposite sign. *This observation is independent of factorization assumption.* As a consequence, if $K^+\pi$ rates are enhanced for $\cos\gamma < 0$, the $\pi^+\pi^-$ rate gets suppressed. In contrast, the $\pi^+\pi^0$ mode is mainly T plus small EWP terms, hence its γ dependence is weak. Analogous to the $K\pi$ case, u and d quark masses enter through R_1. We plot Br vs. γ for $\pi\pi$ modes in Fig. 1(b) for $m_d = 2m_u = 3$ and 6.4 MeV. These quark masses are at the m_b scale, and are within the range given by Particle Data Group [6]. It is clear that $\pi^+\pi^- < \pi^+\pi^0$ is not impossible for $\cos\gamma < 0$ if $m_{u,d}$ are on the lighter side. In this case, however, P would become comparable to T, complicating mixing dependent CP study in $B^0 \to \pi^+\pi^-$ channel. We note that in general the $\pi^0\pi^0$ mode is very small, which would not be the case if $\pi^+\pi^-$ is suppressed by rescattering into $\pi^0\pi^0$.

The $\rho^0\pi^+$ mode has just been observed at the sizable rate of $(1.5 \pm 0.5 \pm 0.4) \times 10^{-5}$ [3], and is seemingly larger than $\omega^0\pi^+ \sim 1 \times 10^{-5}$ as indicated in [2]. Both are at odds with the results of Ref. [5] for $N_C = 3$. Can changing the sign of $\cos\gamma$ help? Dropping EWP terms (but not numerically), the $B^- \to \rho^0\,(\omega^0)\,\pi^-$ amplitude is

$$\mathcal{A}_{V^0\pi^-} = G_F m_V \varepsilon\cdot p_\pi\,\{f_\pi A_0\,[V_{ud}^* V_{ub} a_1 - V_{td}^* V_{tb}(a_4 + a_6 Q_1)] + f_V F_1\,[V_{ud}^* V_{ub} a_2 \pm V_{td}^* V_{tb} a_4]\}\,,$$

where $Q_1 = -2m_\pi^2/(m_b + m_u)(m_u + m_d)$ is opposite in sign to R_1 of Eq. (1), $A_0 = A_0^{BV}(m_\pi^2)$ and $F_1 = F_1^{B\pi}(m_V^2)$ are BSW form factors [5]. The $+/-$ sign for the last term is for ρ^0/ω^0, and is traced to the $d\bar{d}$ content (PDG convention) of ρ^0 and ω^0 when π^+ comes from the spectator quark in a $\bar{b} \to \bar{d}d\bar{d}$ transition. As shown in Fig. 2(a), it splits $\rho^0\pi^+$ upwards from $\omega^0\pi^+$ for $\cos\gamma < 0$. Because the difference between the two amplitudes is otherwise minute, this is a test for $\cos\gamma < 0$ independent of normalization.

The normalization is still of some concern for $N_C = 3$. To see how it might come about, we note that the $a_4 + a_6 Q_1$ term fortuitously cancels to within 10% for $m_u + m_d = 9.6$ MeV.

But if $m_u+m_d = 4.5$ MeV for example, then $a_4+a_6Q_1 > -a_6 > 0$ which would push up $\rho^0\pi^+$ and $\omega^0\pi^+$ for $\cos\gamma < 0$ (see Fig. 2(a)). Scaling up $f_\pi A_0^{BV}$ now by $\sim$ 20–30% brings these rates above 1×10^{-5}. For higher m_u+m_d values a larger $f_\pi A_0^{BV}$ value is needed. The other possibility of scaling up $f_V F_1^{B\pi}$ runs against the (updated [4]) limit $\phi^0 K^+ < 0.59\times 10^{-5}$, which is proportional to $f_\phi F_1^{BK}$ in amplitude. This mode is also plotted in Fig. 2(a), and a slight reduction of $f_\phi F_1^{BK}$ seems to be needed. The $\phi^0 K^+$ rate is unaffected by $m_{u,d,s}$ since the ϕ^0 vector meson cannot come from the spectator quark in B^+ decay.

For $\cos\gamma > 0$ and $N_{\rm eff.} = 3$ (2) one expects [5] the combined $\rho^\pm\pi^\mp$ (separating B^0 from $\bar{B}^0$ decay requires tagging) and $\rho^+\pi^0$ rates to be $\sim$ 7 (4) and 3 (2) times the $\rho^0\pi^+$ rate, respectively, which are very sizable. It is interesting that, while the $\rho^0\pi$ rates are enhanced for $\cos\gamma < 0$, the $B\to\rho^+\pi$ rates are suppressed. Thus, lower $\rho^+\pi^-/\rho^0\pi^+$ and $\rho^+\pi^0/\rho^0\pi^+$ ratios would also suggest that $\cos\gamma < 0$ is preferred. We plot these effects in Fig. 2(b), again for $m_d = 2m_u = 3$ and 6.4 MeV. Note that the $B^0\to\rho^+\pi^-$ mode is insensitive to $m_{u,d}$. The combined $Br(B^0\to\rho^\pm\pi^\mp)$ is still likely to be over 4 times larger than $\rho^0\pi^+$, and since the final state contains only one π^0, it should be observed soon [See Note Added.].

Experimental sensitivities in $\rho\pi$, $K^*\pi$ and ρK modes are similar. With the $\rho^0\pi^+$ observation, a limit on $K^{*0}\pi^+$ is also reported. The event yields [3] suggest that $K^{*0}\pi^+ > \rho^0\pi^+$ is unlikely, which seems again at odds with factorization results [5] for $\cos\gamma > 0$. While too early to draw a conclusion, our earlier argument suggests that $\rho^0\pi^+ > K^{*0}\pi^+$ is possible for $\cos\gamma < 0$, especially since $K^{*0}\pi^+$ is insensitive to γ and perhaps suppressed by $f_{K^*}F_1^{B\pi}$ like the ϕK mode. We plot all the $K^*\pi$ modes in Fig. 3(a). The γ dependence is similar to the $K\pi$ modes of Fig. 1(a), but there is no sensitivity to m_s since K^* is produced by vector currents. Thus, independent of m_s and normalization, we predict that $K^{*+}\pi^- > K^{*+}\pi^0 \sim K^{*0}\pi^+$ [See Note Added.] for $\cos\gamma < 0$, while $K^{*0}\pi^0$ is $\sim$ factor of two lower. In contrast, $\gamma \simeq 60^\circ$–70° [7] would give $K^{*0}\pi^+ \sim K^{*+}\pi^- > K^{*+}\pi^0 \gtrsim K^{*0}\pi^0$.

The ρK modes are analogous to $K^*\pi$ but with vector meson coming from the spectator quark. The tree contribution is color suppressed, so the rates are very sensitive to the penguin combination of $a_4 + a_6 Q$, where $Q = -2m_K^2/(m_b+m_q)(m_q+m_s)$. For $m_s = 105$

MeV, this term again largely cancels. Together with smaller form factors, the ρK modes are in general much lower than the $K^*\pi$ modes, with $\rho^0 K^0$ the largest for $\cos\gamma < 0$. The cancellation between a_4 and a_6, however, is less effective for *larger* m_s, which could enhance (suppress) the ρK^+ (ρK^0) modes considerably for $\cos\gamma < 0$, as can be seen from Fig. 3(b). Thus, they could provide useful tests for m_s. Note that if the prominence of $\rho^0\pi^+$ is in part due to a larger $A_0^{B\rho}$, then some of the ρK modes could be $\sim 0.5 \times 10^{-5}$. However, these modes are too sensitive to m_s for one to make firm predictions.

For the very prominent $\eta' K$ modes, the $g^* \to g\eta'$ "anomaly" effect [12] that seems to account for semi-inclusive $B \to \eta' + X_s$, though still controversial, has to be treated properly. However, we do not know how to treat the possible $|\bar{s}gq\rangle$ Fock component of the K meson. Since in general penguins dominate, the rates are not very sensitive to γ, but one still has the nice feature that $\eta' K^+$ could be enhanced by 10–20% over $\eta' K^0$ for $\cos\gamma < 0$.

Direct CP asymmetries ($a_{\rm CP}$) can arise via penguin absorptive parts. The $K\pi$ modes have been discussed elsewhere [9]. The CP eigenstate $\pi^+\pi^-$ may have $a_{\rm CP} \sim 15$ (10) % for $\cos\gamma <$ (>) 0, opposite in sign to that of $K^{(*)}\pi$ modes, and measurement requires tagging [13]. The $a_{\rm CP}$ for $\pi^+\pi^0$ is very small since strong penguin is absent by isospin symmetry. The $K^*\pi$ and $\rho\pi$ modes are interesting since T/P and P/T are respectively of order 20–30%. As shown in Fig. 4, $a_{\rm CP}$s for $\cos\gamma < 0$ would be smaller (larger) in $K^{*+}\pi$ and $\rho\pi^+$ ($\rho^+\pi$) compared to $\cos\gamma > 0$ case [14], and would again test our conjecture. The $a_{\rm CP}$s for $K^{*0}\pi$ are small, but like $K^0\pi$ modes a sizable $a_{\rm CP}$ would signal the presence of FSI phases [9]. The large $a_{\rm CP}$ in $\rho^0\pi^0$ corresponds to a very small rate and requires tagging to measure.

We offer some remarks before closing. First, as shown in Fig. 2(a), we are still unable to account for the $\omega^0 K^+$ rate [2]. However, at the present level of statistics, and out of $\mathcal{O}(10)$ measurements or limits, having a problem or two is perhaps a virtue. Second, we have not discussed VV modes. They in general depend on several $B \to V$ form factors, while their detection would likely come after prominent PP and VP modes. There is some indication for the ϕK^* mode [2], but being pure $b \to s$ penguin, it has little bearing on γ. Third, the electroweak penguins have been numerically included. They are in general less significant

than varying $\cos\gamma$. Four, larger a_2 (or lower $N_{\rm eff.}$) can [5] enhance $h^+\pi^0$ ($h = \pi$, K, ρ and K^*) and $\rho^0\pi^+$, $\omega^0\pi^+$ modes. Five, although we have kept a range for light quark masses, we note that for $\cos\gamma < 0$, lower m_u, m_d and m_s values lead to interesting results such as further suppressing (enhancing) the $\pi^+\pi^-$ ($\rho\pi^+$ and $\omega^0\pi^+$) mode(s), but making the ρK modes difficult to predict. They also suggest the ordering $K^+\pi^- > K^0\pi^+ \simeq K^+\pi^0 > K^0\pi^0$ for the $K\pi$ modes. Finally, it is surprising that factorization seems to account for present data if one simply changes $\cos\gamma$ from positive to negative, although the latter change runs against fits to KM matrix elements [7]. That something as simple as factorization would work for rare hadronic B decays should be welcome, and it is further encouraging that the conjecture can be tested as more data unfolds, where one can perhaps even contemplate making a more systematic fit to model parameters in the near future. If the $\cos\gamma$ value from such fits continues to be at odds with updated CKM fits, we may be in store for some exciting physics at the B Factories or elsewhere. For example, $\sin 2\beta$ would be lower than the CKM fit prediction and more consistent with $\cos\gamma < 0$, and B_s mixing would be measured soon at the Tevatron and/or SLD, or else we may have new physics.

In conclusion, we find the surprising result that *a simple change in sign for* $\cos\gamma$ *from current fit values can account for present rare B decay data within factorization approximation.* The size of the $K\pi$ modes and the newly observed $\rho^0\pi^+$ mode, the absence of $\pi^+\pi^-$ (perhaps below $\pi^+\pi^0$) etc., can all be due to having constructive rather than destructive tree-penguin interference, or vice versa. Prominence of $\rho^0\pi^+$ probably implies a larger A_0^{BV} form factor, while absence of ϕ^0K^+ suggests a smaller F_1^{BP}, which may also contribute to the absence of $K^{*0}\pi^+$. Chief predictions for $\cos\gamma < 0$ are: $\rho^0\pi^+ > \omega^0\pi^+$, $K^{*+}\pi^- > K^{*0}\pi^+$, reduced but still prominent $\rho^+\pi^-/\rho^0\pi^+$ and $\rho^+\pi^0/\rho^0\pi^+$ ratios, and $K^+\pi^- > K^0\pi^+$ if m_s is on lighter end. One expects a lower $\sin 2\beta$ value at B Factories compared to current fit results, and B_s mixing close to present LEP bounds..

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Note Added.

After this work was posted, CLEO announced [15] the measurement of $Br(B \to \rho^\pm \pi^\mp) = (3.5^{+1.1}_{-1.0} \pm 0.5) \times 10^{-5}$ and $Br(B \to K^{*+}\pi^-) = (2.2^{+0.8+0.4}_{-0.6-0.5}) \times 10^{-5}$, which further confirm our conjecture that $\cos\gamma < 0$. The ratio $\rho^\pm\pi^\mp/\rho^0\pi^+ \simeq 2.3$ turns out to be less than 4 which we had advocated. From hindsight, since $\mathcal{A}(B^0 \to \rho^+\pi^-) \propto F_1^{B\pi}$, this can be attributed to our observation that A_0^{BV} is enhanced to account for $\rho^0\pi^+$ rate, while $F_1^{B\pi}$ is suppressed as indicated by $\pi^+\pi^-$ and ϕK^+ nonobservation.

REFERENCES

[1] J. Alexander, plenary talk at ICHEP98, Vancouver, August 1998.

[2] T. Bergfeld et al. (CLEO Collaboration), Phys. Rev. Lett. **81**, 272 (1998). The $\omega^0\pi^+$ mode, though weaker than $\omega^0 K^+$, is also of order 1×10^{-5}.

[3] Y.S. Gao, CLEO talk presented at DPF99, Los Angeles, January 1999.

[4] F. Würthwein, CLEO talk presented at DPF99, Los Angeles, January 1999.

[5] See, for example, A. Ali, G. Kramer and C.D. Lü, Phys. Rev. **D58**, 094009 (1998); H.Y. Cheng, talk presented at DPF99, Los Angeles, January 1999; Y.H. Chen et al., e-print hep-ph/9903453. Our numerical studies closely follow the latter.

[6] C. Caso et al. (Particle Data Group), Eur. Phys. J. C **3**, 1 (1998).

[7] For recent updates, see A. Stocchi, e-print hep-ex/9902004; S. Mele, hep-ph/9810333; and references therein.

[8] R. Fleischer and T. Mannel, Phys. Rev. **D57**, 2752 (1998).

[9] N.G. Deshpande et al., Phys. Rev. Lett. **82**, 2240 (1999).

[10] See also M. Neubert and J. Rosner, Phys. Lett. **B 441**, 403 (1998).

[11] FSI rescattering could change the relative size of $B^0 \to \pi^+\pi^-$ and $\pi^0\pi^0$. The analysis is similar to the one carried out in Ref. [9].

[12] D. Atwood and A. Soni, Phys. Lett. **B 405**, 150 (1997); W.S. Hou and B. Tseng, Phys. Rev. Lett. **80**, 434 (1998).

[13] N.G. Deshpande and X.G. He, Phys. Rev. Lett. **76**, 360 (1996).

[14] See, for example, A. Ali, G. Kramer and C.D. Lü, Phys. Rev. **D59**, 014005 (1999).

[15] W. Sun, CLEO talk presented at APS Centennial Meeting, Atlanta, March 1999. See also Y.S. Gao and F. Würthwein, e-print hep-ex/9904008.

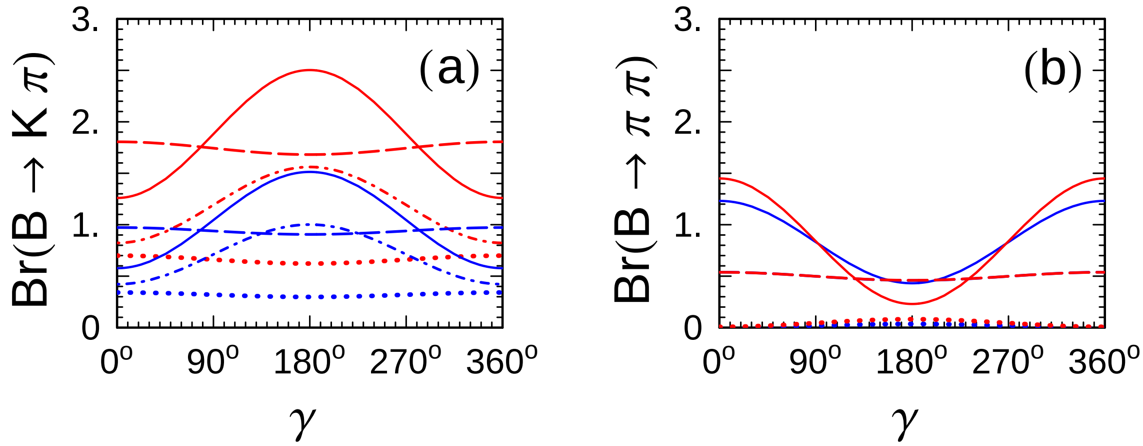

FIG. 1. (a) Solid, dash, dotdash and dots for $B \to K^+\pi^-$, $K^0\pi^+$, $K^+\pi^0$ and $K^0\pi^0$, for $m_s =$ 105 (upper curves) and 200 MeV. (b) Solid, dash and dots for $B \to \pi^+\pi^-$, $\pi^+\pi^0$ and $\pi^0\pi^0$ for $m_d = 2m_u = 3$ and 6.4 MeV, where the lower (upper) curve at $\gamma = 180°$ for $\pi^+\pi^-$ ($\pi^0\pi^0$) is for lower $m_{u,d}$. In all figures Brs are in units of 10^{-5}, and $|V_{ub}/V_{cb}| = 0.08$.

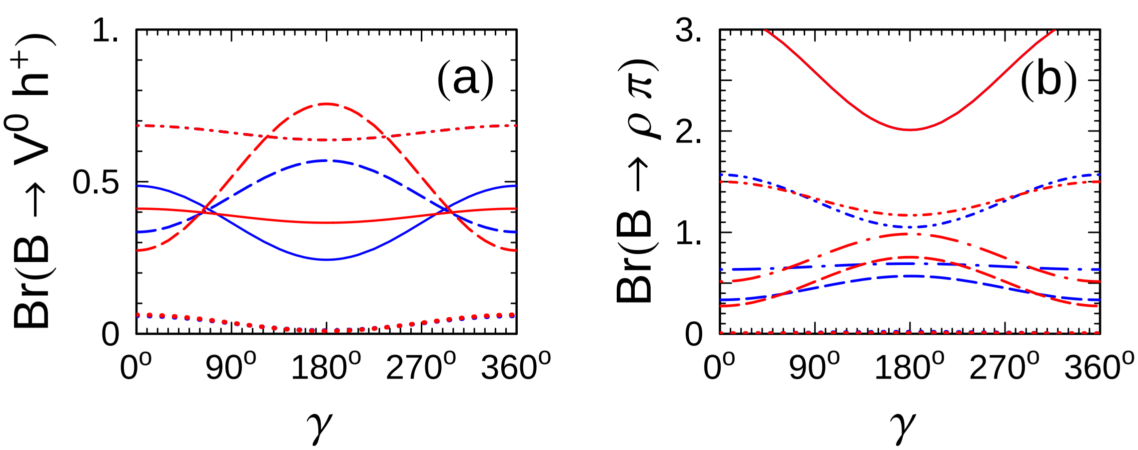

FIG. 2. For $m_d = 2m_u = 3$ and 6.4 MeV, (a) solid, dash, dotdash and dots for $\omega^0\pi^+$, $\rho^0\pi^+$, ϕ^0K^+ and ω^0K^+; (b) solid, short-dotdash, long-dotdash, dash and dots for $B \to \rho^+\pi^-$, $\rho^+\pi^0$, $\rho^-\pi^+$, $\rho^0\pi^+$ and $\rho^0\pi^0$. The upper curves at $\gamma = 180°$ are for lower $m_{u,d}$.

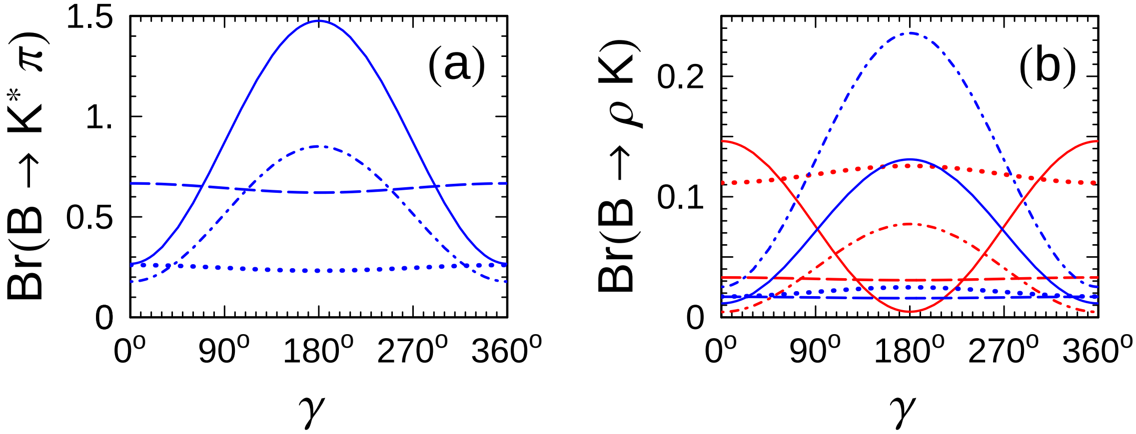

FIG. 3. (a) Solid, dash, dotdash and dots for $B \to K^{*+}\pi^-$, $K^{*0}\pi^+$, $K^{*+}\pi^0$ and $K^{*0}\pi^0$, which are insensitive to m_s. (b) Solid, dash, dotdash and dots for $\rho^- K^+$, $\rho^+ K^0$, $\rho^0 K^+$ and $\rho^0 K^0$, for $m_s = 105$ and 200 MeV. The upper (lower) curves for ρK^0 (ρK^+) at $\gamma = 180^\circ$ are for lower m_s.

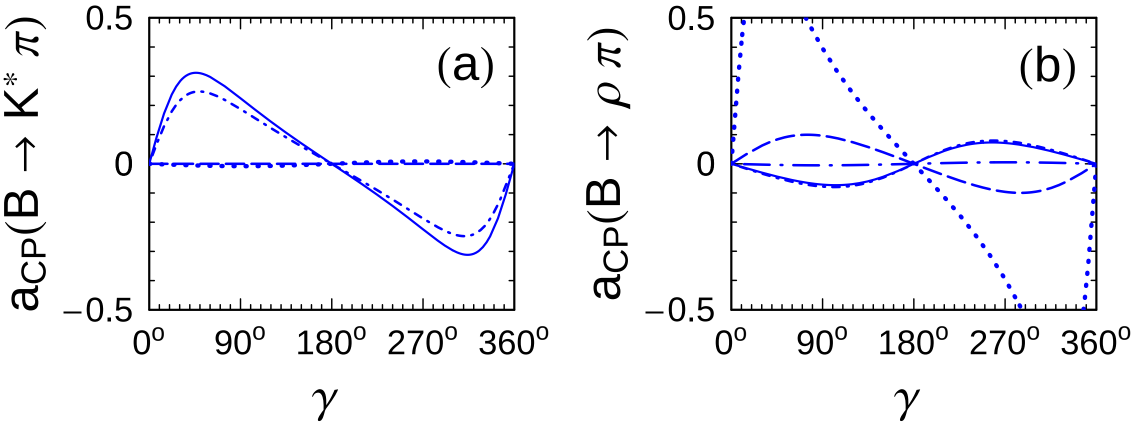

FIG. 4. Direct CP violating asymmetries vs. γ for (a) $K^*\pi$ and (b) $\rho\pi$ modes (for $m_d = 2m_u = 6.4$ MeV), with same notation as in Figs. 3(a) and 2(b), respectively, and with $q^2 = m_b^2/2$ for penguin absorptive parts.